STUDIES ON THE PHENOMENA OF THE EVAPORATION OF WATER OVER LAKES AND RESERVOIRS.

By Prof. FRANK H. BIGELOW. Dated February 1, 1909.

IV.—THE PROGRESS OF THE RESEARCH IN 1908, AND THE PROPOSED CAMPAIGN FOR THE YEARS 1909 AND 1910.

(1) THE EXTENSION OF THE NUMBER OF STATIONS IN THE UNITED STATES.

In the year 1907 an examination of the Salton Sea, southern California, and its neighborhood, was made regarding its availability for an extensive research into the laws controlling the rate of evaporation of water in the open air over large lakes and reservoirs. A short series of observations, from August 1 to September 15, was made in that year at the city reservoir, Reno, Nev., on evaporation from pans located in different parts of the vapor blanket covering the reservoir. The object of this experiment was to determine the influence of the vapor blanket on evaporation. In the subsequent months, September, October, and November, 1907, a series of observations was made at Indio, Riverside County, Cal., about 15 miles north of the Salton Sea,[1] to discover what effect upon the evaporation would be caused by placing several pans in positions near each other, but differently located relatively to the ground, the set being entirely removed from a vapor blanket cover due to a water area. In 1908 the following series of observations were made: (1) July to December, at the Government date garden, Indio, Cal., two pans, one on the ground and one on a stand, 10 feet above the ground; (2) July to October, at the Government date garden, Mecca, Cal., two pans similarly located. Mecca is about one-half mile from the Salton Sea, and the vapor pressure is higher than at Indio or Reno, the mean daily vapor pressure at the dew-point being about 17 millimeters at Mecca, 12 millimeters at Indio, and 7 millimeters at Reno; (3) July, August, a row of pans set in a line perpendicular to the shore of the Salton Sea, extending from the shore into the desert about 1,500 feet, to determine the effect of the overhanging vapor blanket as it thins out in the surrounding dry atmosphere. Whatever results might be obtained in the extremely arid regions just mentioned, it was thought improbable that they could be transferred to the semiarid regions of the West, or to the humid regions of the Eastern and Southern States, without first taking a sufficient number of observations in different climates to check the formula thru this wide range of conditions.

A plan of cooperation was perfected between the United States Weather Bureau, the United States Reclamation Service, and the Water Resources Branch of the United States Geological Survey, by which simultaneous series of observations on the same schedule and plan should be taken at various places in the United States. The Weather Bureau furnishes the evaporation pans, thermometers, anemometers, burette gage tubes, record books, and computation tables, and the cooperating bureaus are to make the observations so far as practicable. Professor Bigelow paid a visit of inspection to the several stations mentioned below during the months July to October, 1908, in connection with his inspection of the climatological section centers of the United States Weather Bureau. At the several "projects" of the United States Reclamation Service it was generally proposed that a 2-pan station should be located immediately on a large water area, that a 2-pan station should be placed in the midst of an irrigated region, e. g., an alfalfa field, and that a 2-pan station should be placed in a dry area apart from natural water surfaces or irrigated ground. These three types of location characterize every irrigation project, and the law of evaporation must be studied under these three characteristic conditions. The following "projects" of the Reclamation Service will take part in the observation in 1909:

	Project.	Place.	County.	State.
1	North Platte.	Mitchell.	Scotts Bluff.	Nebraska.
2	Shoshone.	Powell.	Big Horn.	Wyoming.
3	Minidoka.	Rupert.	Lincoln.	Idaho.
4	Payette-Boise.	Boise.	Ada.	Idaho.
5	Umatilla.	Hermiston.	Umatilla.	Oregon.
6	Sunnyside.	North Takima.	Yakima.	Washington.
7	Klamath.	Klamath Falls.	Klamath.	Oregon.
8	Truckee-Carson.	Fallon.	Churchill,	Nevada.
9	Salt River.	Phoenix.	Maricopa.	Arizona.
10	Engle.	Engle.	Sierra.	New Mexico.
11	Carlsbad.	Carlsbad.	Eddy.	New Mexico.

Also the following reservoirs under the supervision of the United States Geological Survey:

	Reservoir.	Place.	County.	State.
12	Chicago Drainage Canal.	Lockport.	Will.	Illinois.
13	Cincinnati.	California.	Hamilton.	Ohio.
14	East Lake.	Birmingham.	Jefferson.	Alabama.
15	Tupper Lake.	Tupper Lake.	Franklin.	New York.

The following stations[1] are to be established on or near the Salton Sea, California:

	Station.	Place.	County.	State.
16	Salt Creek Trestle.	near Durmid.	Riverside.	California.
17	Mecca.	Mecca.	Riverside.	California.
18	Indio.	Indio.	Riverside.	California.
19	Mammoth.	Mammoth.	San Diego.	California.
20	Brawley.	Brawley.	San Diego.	California.

The number of pans to be under observation is not known exactly, but it will probably exceed one hundred. The plan is to set the entire system of evaporation observations in operation as soon as the milder weather of spring opens up the waters on the Rocky Mountain Plateau, and immediately following the completion of the heavy construction work at the Salton Sea. It is hoped that eventually we may secure a general formula embracing all the conditions involved. Some account of the development of the formula is given in this paper. A "Manual" of instructions for taking the observations and making the computations has been prepared for the use of observers. It contains a series of tables which greatly facilitate the required computations.

(2) ANALYSIS OF THE THEORY AND FORMULA USED IN DISCUSSING THE EVAPORATION OBSERVATIONS.

In calm weather, when the velocity of the wind is zero over a water surface, the columns of vapor which escape from the water in the process of evaporation may be analyzed as constituting a sheaf of tubes, which are concentrated at the water area, but gradually spread out under the lateral hydrostatic pressure and overlay the boundaries of the reservoir or lake in the higher levels. These vapor pressure tubes are illustrated in fig. 32.

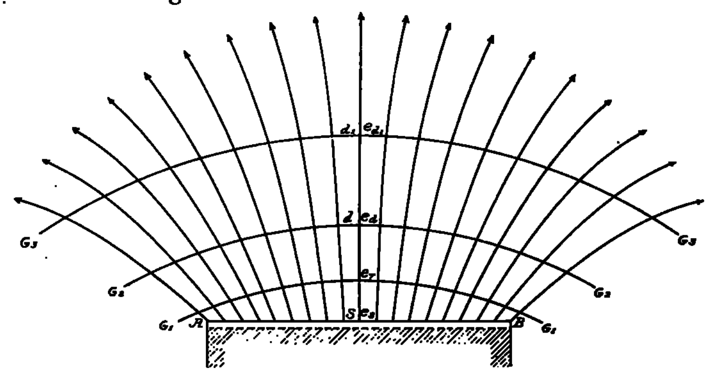

FIG. 32.—Evaporation from a water surface.

AB = the evaporating water surface.

G_1, G_2, G_3 = surfaces of equal vapor pressure.

e_s = vapor pressure of saturation at the temperature S.

e_r = vapor pressure at 1 cm. above the water surface.

e_d = vapor pressure at the dew-point temperature.

$\frac{e_s}{e_r}$, $\frac{e_s}{e_d}$, represent pressure gradients of the vapor escaping along the stream lines.

[1] See map in Monthly Weather Review, July, 1907, 35: Chart IX.

There is a longitudinal vapor pressure acting along these tubes, and another vapor pressure which acts at right angles to them. This hydrostatic pressure is maintained by a flow of the vapor particles in certain masses at a certain ratio along the tubes. A given volume of water can be turned into a definite volume of vapor at a given temperature, and the relations between the volume of water, v_2, and the corresponding volume of vapor, v_1, is exprest in Clapeyron's formula (18), MONTHLY WEATHER REVIEW, July, 1907, 35, p. 314. The rate at which this vapor moves along the tubes at any point depends upon the gradient of the vapor pressure actually existing at any cross section. This gradient is the resultant of a series of physical processes, which, perhaps, can not be fully exprest. These are the bombardment of the vapor molecules from the water surface toward the air, and of the air molecules toward the water. Whatever expression may be derived for the integral of such a double bombardment, the physical result is a certain vapor pressure at each plane or section of the tube. This vapor pressure varies from section to section along the tube, and is measured at the several sections by the ordinary methods of psychrometry. The vapor pressure begins at the foot of the tube with the maximum, which is the vapor pressure of saturation, at the temperature of the water surface S, and here called e_s. This vapor pressure diminishes quite abruptly near the water surface, and falls along the tube to its minimum, which is the vapor pressure at the dew-point temperature of the atmosphere within 1 or 2 feet of the water surface, and this is called e_d. Intermediate between these values of vapor pressure, e_s and e_d, occur other values of e, called e_r, and the rate of fall of the vapor pressure or its gradient per centimeter can be studied by measuring such values of e_r as lie between e_s and e_d.

Practically, a Centigrade thermometer with a glass jacket was floated, just submerged, in the water, and its temperature S is the argument for e_s in the Smithsonian Table No. 43.[1] On a small raft at the height of one centimeter above the water surface, a dry-bulb thermometer and a wet-bulb thermometer were floated, and from their readings the values e_r were computed. The values of e_d were determined by the sling psychrometer for a distance of one or two feet above the water surface. This method, employed at Reno, Nev., gave us numerous examples for studying the entire subject. When the weather is not calm, and the wind is blowing at w kilometers per hour, the effect is to break up these tubes, so that new ones are forming close to the water surface to be distorted, broken, carried away in the wind, and to be converted into the heterogenous mass of shattered tubes called roughly the vapor pressure at the dew point. These tubes may be conceived as forming all over a water area. In a wind the tubes on the windward side are carried forward to accumulate more or less thickly on the leeward side, where the vapor pressure should be greater. Hence, evaporation is more rapid on the windward side than on the leeward side of a water area. This complication, due to the wind, is called the wind effect, and it is expressed by the term,

$$A\, E_1\, w = 0.0175\, E_1\, w,$$

where E_1 is the evaporation in a calm. The constant coefficient, $A = 0.0175$, was determined at Reno, Nev., but it will be verified on the towers at the Salton Sea. For the present we have

$$E_w = E_1\,(1 + 0.0175\, w).$$

The most important purpose to keep in mind, during the search for an evaporation formula, is that it shall be simple in practice. Much of the success of the work depends upon the possibility of accomplishing this result. The following explanation of the theory of this research applies this principle, and a simple formula that will follow accurately the subtle and complex variations of the amount of evaporation, as illustrated by the observations already made, is greatly to be desired. The formula for calm weather divides itself into at least four parts, (1) a set of physical constants, (2) the time factor, (3) an expression for the mass of water evaporated, and (4) the gradient of the vapor pressure. As the first two terms give no special trouble in themselves, our attention may be fixed upon the last two terms, Mass and Gradient.

Mass. The Clapeyron formula is written,

$$v_1 - v_2 = \frac{r_2}{T} \cdot \frac{dT}{de} \times \frac{41855000 \times 760}{1013240}.$$

In this formula the notation signifies

v_1 = the volume of vapor.
v_2 = the volume of water.
r_2 = the latent heat of water at the temperature T.
T = $273 + S$ = the absolute temperature of the water surface.
$\frac{de}{dT} = \frac{de}{dS}$ = the rate of change of the vapor pressure in the saturated condition, with the temperature.
41855000 = the mechanical equivalent of heat in ergs.
760 = the pressure of one atmosphere in millimeters.
1013240 = the pressure of one atmosphere in dynes.

The ratios $\frac{r_2}{T}$ and $\frac{de}{dS}$ can be derived from ordinary physical tables and with the values of v_1 derived from $v_2 = 1$ cubic centimeter of water are shown in Table 23.

TABLE 23.—*Evaluation of the terms in Clapeyron's formula.*

T	r_2	$\frac{r_2}{T}$	$\frac{de}{dS}$	v_2	v_1
° 273	606.5	2.22	0.330	1	211356
283	599.4	2.12	0.610	1	109006
293	592.3	2.02	1.075	1	59312
303	585.3	1.93	1.815	1	33507
⋮	⋮			⋮	⋮
373	535.7			1	1659

From this table we see that for ordinary atmospheric temperatures v_2 is relatively so small that it may be neglected in the expression $v_1 - v_2$. Furthermore, the ratio $\frac{r_2}{T}$ is nearly constant and may be assumed equal to 2 with little error for the atmospheric temperatures at which evaporation takes place vigorously, namely, from 10° to 30° C. It is evident that

$$dT = d(273 + S) = dS.$$

Transposing the Clapeyron formula, it thus becomes

$$\frac{de}{dS} = \frac{1}{v_1} \times \frac{2 \times 41855000 \times 760}{1013240} = \frac{1}{v_1} \times 62798.$$
$$= \rho_1 \times \text{constant}.$$
$$= \text{mass per unit volume} \times \text{constant}.$$

Hence, $\frac{de}{dS}$ is approximately proportional to the mass that passes thru the vapor tube from the surface of the water to the free air. The advantage of this expression for mass is that it is easily derived from the surface temperature, S, of the water surface as determined by the floating submerged thermometer. $\frac{de}{dS}$ is obtained from Smithsonian Meteorological Table 43 by subtracting the vapor pressure e for suc-

[1] Smithsonian meteorological tables. Third revised edition. Washington, 1907. Table 43, p. 142.

cessive degrees C. and taking the mean of the values for the observed temperatures S as the rate of change of the vapor pressure per degree. The rate of the evaporation at any temperature is proportional to this term $\frac{de}{dS}$, except so far as it is controlled by the passage of the vapor along a tube which contains a mixture of dry air and vapor gas. The flow of the vapor pressure in the tube is dependent upon the gradient, and this is measured by the vapor pressure from section to section.

Gradient.—It was thought that by measuring the vapor pressure at the water surface, e_s, and at a distance of one centimeter above it, e_r, some knowledge regarding this vapor pressure gradient might be obtained. As the result of several extensive computations on the Reno, Indio, and Mecca observations, it was decided to continue the research with the following evaporation formula,

$$E_o = C_d \times 0.100 \frac{e_s}{e_d} \cdot \frac{de}{dS} (1 + Aw).$$

It will be noted that the vapor pressure e_r does not appear in the formula, but that the vapor pressure at the dew-point temperature has taken its place. The computations were first conducted by means of the ratio $\frac{e_s}{e_r}$, but it was found that the ratio $\frac{e_s}{e_d}$ works equally well, tho of course the coefficient C_d has another value. For the Reno observations the value of the coefficient for 4-hour intervals is about 0.100 and the variations can be expressed in terms of a small coefficient, C_d, which is still to be determined. Since E_o is the observed evaporation and all the terms except C_d are found by direct instrumental observation, we have,

$$C_d = \frac{E_o}{0.100 \frac{e_s}{e_d} \cdot \frac{de}{dS} (1 + Aw)} = \frac{E_o}{E_1 + E_1 Aw} = \frac{E_o}{E_1 + E_2}.$$

A "Manual for Observers in Climatology and Evaporation" has been prepared in which are found tables for computation and examples, besides such descriptions as will make the procedure clearly understood by observers. Tables I and II are for computing e_d; Table III for e_s; Table V for $\frac{de}{dS}$; Table VI for E_1, and Table VII for E_2.

The equation

$$E_1 = 0.100 \frac{e_s}{e_d} \cdot \frac{de}{dS}$$

gives the evaporation in four hours under the temperature conditions of the atmosphere and the water in a calm; and $E_1 = E_0$ whenever $C_d = 1.00$.

The equation

$$E_2 = E_1 Aw = 0.100 \frac{e_s}{e_d} \cdot \frac{de}{dS} \times 0.0175\, w,$$

shows the effect of the wind on the amount evaporated in four hours. Since e_s and $\frac{de}{dS}$ are directly functions of S the term E_1 is found thru the arguments S and e_d; E_2 is computed thru the arguments E_1 and w. If the coefficient C_d were constant the formula would be simple and satisfactory, as will be shown. It seems to be a variable, and it is the next step in the research to discover its function. In thus assuming trial functions for one term after another, and discussing their capability to follow the observations made under numerous conditions of evaporation, we shall gradually approach the function which will be adopted for the entire phenomena in nature.

There are two reasons for employing the ratio $\frac{e_s}{e_d}$ in the formula instead of the ratio $\frac{e_s}{e_r}$. The sling psychrometer is preferred as an instrument to the floating raft psychrometer, and it is in the hands of all meteorologists. The dry-bulb thermometer on the raft is liable to get wet in rough water, and thus spoil the observation. The floating submerged thermometer and the sling psychrometer are not open to this criticism.

The ratio $\frac{e_s}{e_d}$ needs a word of comment. In the Dalton formula the difference $e_s - e_d$, may approach the value 0, and this would imply that evaporation ceases when $e_s = e_d$. It is, however, probable that even when $e_s = e_d$, and the vapor pressure in the air is the same as that at the water surface, there is a flow of vapor in the tubes required to maintain the vapor pressure e_d near the water. If the above ratio is used it may become $\frac{e_s}{e_d} = 1$ at the limit, but this will permit an evaporation represented by $\frac{de}{dS}$ to continue. It was shown at Reno that the evaporation continues vigorously during the night even when e_d is nearly equal to e_s. The product $\frac{e_s}{e_d} \cdot \frac{de}{dS}$ is so nearly proportional to the observed evaporation at Reno as to suggest that C_d is a constant. This is not really the case because C_d is different at the three stations, Mecca, Indio, and Reno, indicating that the true function requires a further modification of some kind. Illustrations of the working of the formula will be given, which tend to elucidate the phenomena of evaporation in the open air.

(3) EXAMPLES OF THE USE OF THE EVAPORATION FORMULA.

In the MONTHLY WEATHER REVIEW, February, 1908, **36**, p. 34–39, were given some examples of the action of Bigelow's first formula for the amount of evaporation observed at 3-hour intervals at Reno, Nev., August 1 to September 15, 1907. At that station five towers were erected at a double reservoir, and a series of pans were placed on each tower at 10-foot intervals extending from the water surface to 45 feet above it. The general result was that the C-coefficient had an interesting but large variation in the system, indicating that a satisfactory formula had not been secured. For the purpose of eliminating this variation, by introducing a different function for the vapor pressure relations, Bigelow's second formula was developed, and the account of it here given, while very brief, shows that the variation of the C-coefficient has been greatly reduced, tho it has not been fully accounted for by this formula, It is hoped that the campaign of 1909 will enable us to analyze the remaining variation, and thus complete the formula. The Dalton formula depends upon the difference of the vapor pressure, $e_s - e_d$, while Bigelow's first formula depended simply upon e_d, and the second upon the ratio e_s/e_d, as already explained, to express the gradient term. There was some doubt whether the ratio should be e_s/e_r or e_s/e_d, but it has been decided that the latter is the proper one to be used in practical work, In addition to illustrating the relations between the C_d-system, using the ratio e_s/e_d, and the C_r-system, using the ratio e_s/e_r, examples are given of the computations by following the formula strictly, and the corresponding computations by using the tables contained in the Manual for Observers in Climatology and Evaporation, to be issued by the Weather Bureau in 1909. These tables simplify the computation very much, and in connection with the Record Book supplied by the Weather Bureau to observers, make the computing as compact as possible, Crelle's multiplication tables are needed.

Computation by formula.

Table 24 illustrates the computation of the observations at Reno, Nev., tower 2, pan 1, August 12–17, 1907, by the formula

$$E_o = C_d \cdot \frac{e_s}{e_d} \cdot \frac{de}{dS}(1 + Aw).$$

In this table

$$C_d = \frac{E_o}{\frac{de}{dS} \cdot \frac{e_s}{e_d}\,(1 + Aw)}.$$

S = temperature of the water surface.

e_s = vapor pressure at the temperature S.

e_d = vapor pressure at the dew-point d.

w = mean velocity of the wind in kilometers per hour.

E_o = observed evaporation for three hours.

$\frac{de}{dS}$ = expression for the mass. (Use Manual Table V.)

$\frac{e_s}{e_d}$ = expression for the gradient. (Use Crelle's tables.)

$(1 + Aw)$ = Expression for the wind effect. $A = 0.0175$.

Product = the three preceding terms multiplied together.

Means = the mean values of the successive pairs on the line of products.

C_d = the coefficient which contains the thermodynamic constants, the time elapsed for the evaporation interval and some unknown function, e. g., diffusion.

TABLE 24.—*Examples of the computations by the formula,*

$$E_o = C_d \cdot \frac{e_s}{e_d} \cdot \frac{de}{dS}\,(1 + Aw).$$

Reno, Nevada, tower 2, pan 1, August 12–17, 1907.

Term.	A. M.				P. M.				Sum.	Means.
	2	5	8	11	2	5	8	11		
S	15.3	15.7	18.6	22.2	22.2	19.9	17.3	16.0	....	18.4
e_s	12.9	13.3	15.9	19.9	19.9	17.3	14.7	13.5	....	15.9
e_d	7.1	7.3	8.1	7.5	8.0	7.6	6.9	7.0	....	7.4
w	12	7	3	9	13	25	23	17	....	14
E_o	0.110	0.100	0.105	0.155	0.210	0.190	0.170	0.140	1.180	0.148
de/dS	0.83	0.85	1.00	1.21	1.21	1.07	0.93	0.86	....	1.00
e_s/e_d	1.82	1.82	1.96	2.65	2.49	2.28	2.13	1.93	....	2.14
$(1 + Aw)$	1.21	1.12	1.05	1.15	1.23	1.44	1.40	1.30	....	1.24
$e_s/e_d \cdot de/dS$	1.51	1.55	1.96	3.21	3.01	2.44	1.98	1.66	....	2.17
Product	1.83	1.73	2.06	3.69	3.70	3.51	2.77	2.16	21.45	2.68
Means	2.00	1.78	1.90	2.88	3.70	3.61	3.14	2.47	....	....
C_d	0.055	0.056	0.055	0.054	0.057	0.053	0.054	0.057	0.55	0.055

Computation by tables.

The same example, arranged for computing by the aid of the tables in the Manual, is shown in Table 25, where

$E_1 = 0.100 \cdot \frac{de}{dS} \cdot \frac{e_s}{e_d}$, = the evaporation in calm periods.

$E_2 = E_1 Aw$, = the wind effect.

$E = E_1 + E_2 = E_1\,(1 + Aw)$.

E_m = means of two successive values of E.

E_o = the observed evaporation in three hours.

TABLE 25.—*The same example arranged for computation by the tables.*

Term	A. M.				P. M.				Sum.	Means.
	2	5	8	11	2	5	8	11		
S	15.8	15.7	18.6	22.2	22.2	19.9	17.3	16.0	....	18.4
e_d	7.1	7.8	8.1	7.5	8.0	7.6	6.9	7.0	....	7.4
w	12	7	3	9	13	25	23	17	....	14
E_1	0.15	0.15	0.20	0.32	0.30	0.24	0.20	0.17	....	0.22
E_2	.03	.02	.01	.05	.07	.11	.08	.05	....	.05
E	.18	.17	.21	.37	.37	.35	.28	.22	....	.27
E_m	.200	.175	.190	.290	.370	.365	.315	.250	....	....
E_o	.110	.100	.105	.155	.210	.190	.170	.140	1.180	.148
0.100 C_d	.055	.057	.055	.053	.057	.052	.054	.056	.055	.055

TABLE 26.—*The same example arranged for computation by the tables, but using e_r instead of e_d.*

Terms.	A. M.				P. M.				Sum.	Means.
	2	5	8	11	2	5	8	11		
S	15.3	15.7	18.6	22.2	22.2	19.9	17.3	16.0	....	18.4
e_r	9.4	9.3	12.0	12.1	11.1	12.2	9.7	9.5	....	10.7
w	12	7	3	9	13	25	23	17	....	14
E_1	0.11	0.12	0.13	0.20	0.22	0.15	0.14	0.12	....	0.15
E_2	.02	.01	.01	.03	.05	.07	.06	.04	....	.04
E	0.130	0.130	0.140	0.230	0.270	0.220	0.200	0.160	....	0.190
E_m	0.145	0.130	0.135	0.185	0.250	0.245	0.210	0.180	....	....
E_o	0.110	0.100	0.105	0.155	0.210	0.190	0.170	0.140	1.180	0.148
0.100 C_r	0.076	0.077	0.078	0.084	0.084	0.078	0.081	0.078	0.079	0.078

These three examples of computation with the same data of observation are given for the sake of illustration the method of procedure. In Table 24 the computation is carried thru by means of Crelle's multiplications tables; in Table 25 it is per-

TABLE 27.—*Observations at Reno, Nev., August 12–17, 1907. Comparison of the computed coefficients C_d and C_r.*

Tower.	A. M.				P. M.				Means.
	2	5	8	11	2	5	8	11	
C_d for Pan 1.									
Tower 2.......	.055	.055	.056	.055	.060	.055	.055	.056	.056
Tower 3.......	.055	.054	.059	.057	.052	.056	.054	.060	.055
Tower 4.......	.055	.050	.051	.064	.059	.060	.061	.062	.058
Mean C_d.......	.055	.053	.055	.059	.057	.057	.057	.059	.056
C_r for Pan 1.									
Tower 2.......	.076	.076	.078	.079	.084	.078	.081	.078	.079
Tower 3.......	.076	.076	074	.076	.081	.073	.071	.072	.076
Tower 4.......	.067	.066	.068	.077	.077	.080	.073	.071	.072
Mean C_r.......	.073	.073	.073	.077	.081	.080	.075	.074	.076
C_d for Pan 3.									
Tower 2.......	.062	.085	.074	.068	.071	.061	.059	.068	.069
Tower 3.......	.077	.083	.074	.055	.057	.062	.068	.070	.068
Tower 4.......	.072	.084	.087	.072	.064	.070	.071	.064	.073
Mean C_d.......	.070	.084	.078	.065	.064	.064	.066	.077	.070
C_r for Pan 3.									
Tower 2.......	.085	.108	.105	.107	.100	.084	.087	.098	.097
Tower 3.......	.100	.105	.102	.085	.077	.074	.083	.090	.090
Tower 4.......	.086	.091	.100	.088	.080	.078	.077	.077	.085
Mean C_r.......	.090	.101	.102	.097	.086	.079	.082	.088	.091
C_d for Pan 5.									
Tower 2.......	.056	.069	.069	.072	.070	.075	.067	.068	.068
Tower 3.......	.064	.076	.073	.065	.068	.073	.076	.072	.072
Tower 4.......	.073	.078	.077	.058	.063	.063	.079	.076	.071
Mean C_d.......	.064	.074	.073	.065	.067	.070	.074	.072	.070
C_r for Pan 5.									
Tower 2.......	.081	.100	.102	.118	.105	.104	.093	.098	.100
Tower 3.......	.094	.098	.100	.088	.081	.095	.108	.093	.095
Tower 4.......	.088	.091	.103	.096	.104	.091	.102	.098	.097
Mean C_r.......	.088	.096	.102	.101	.097	.097	.101	.096	.097
C_d for Pan 7.									
Tower 2.......	.062	.077	.073	.071	.074	.070	.061	.063	.069
Tower 3.......	.076	.075	.073	.058	.052	.066	.083	.072	.071
Tower 4.......	.069	.077	.065	.065	.068	.071	.073	.065	.069
Mean C_d.......	.069	.076	.070	.065	.065	.069	.072	.067	.070
C_r for Pan 7.									
Tower 2.......	.091	.097	.104	.112	.115	.096	.095	.093	.100
Tower 3.......	.098	.106	.109	.086	.077	.093	.107	.091	.096
Tower 4.......	.103	.103	.092	.102	.098	.091	.094	.097	.098
Mean C_r.......	.097	.102	.102	.100	.097	.093	.099	.094	.098

formed by means of the tables in Bigelow's Manual; in Table 26 the system is changed from $\frac{e_s}{e_d}$ which gives C_d to $\frac{e_s}{e_r}$ which gives C_r. It is noted that the coefficients are nearly alike thruout the twenty-four hours, and this indicates that the diurnal variation of the evaporation has been eliminated. It will be shown that the variation of the evaporation between 10 and 45 feet above the water on the towers at Reno has also been eliminated by this formula. Unfortunately the C-coefficient is not constant from the water surface up to about 10 feet in height, nor is it constant from one climate to another. The probability is that the formula lacks one term. By substituting the vapor pressure e_r for e_d the computation for C_r shows that at Reno, Nev.,

$$\frac{C_r}{C_d} = \frac{0.079}{0.056} = 1.41.$$

The purpose of a formula is to eliminate, (1) the diurnal variation at a given pan, (2) the vertical variation on a tower at a given place, (3) the horizontal variation over a given reservoir, (4) the general variation due to changes in latitude and longitude. These steps will be more fully illustrated by extracts from our computed results.

The irregularities in the above computed values of C_d and C_r can be referred to imperfections in the observations. It is noted that both systems tend to produce constants thruout the day, thus showing that the diurnal variation is eliminated. The ratios of C_r/C_d for the several pans are as follows: Pan (1), 1.36; pan (3), 1.30; pan (5), 1.39; pan (7), 1.40; the mean of which is 1.36. Similar results, obtained from the observations at Indio and Mecca, lead to the conclusion that the vapor pressure at the dew-point temperature e_d, as obtained by the sling psychrometer, can be substituted for the vapor pressure e_r, as found by the stationary psychrometer floating on the raft. This obviates the necessity of securing vapor pressures at fixt planes above a water surface within the limits of 2 or 3 feet, and the raft can be placed in very rough water without guarding the upper thermometers from wave washing, since only the reading of the submerged thermometer S is required. The arguments for Table VI of the Manual are S and e_d; those for Table VII of the Manual are E_1 and w.

(4) THE DETERMINATION OF THE C_d-COEFFICIENT AT SEVERAL LOCALITIES.

It is important to establish the relations of the C_d-coefficient to bodies of water and to soils in various climates, with the hope of determining the form of the function that is concealed within it, in the symbol C_d. A series of examples from the observations will be summarized and the conclusions stated as they seem to be justified. It is not practicable to reproduce the original observations for S, the surface temperature; e_d, the vapor presssure of the dew-point; w, the wind velocity in kilometers per hour, and E_o, the observed evaporation for the interval; but only the computed C_d for several series of observations, *i. e.:*

1. Evaporation from a small *reservoir*, Reno, Nev.
2. Evaporation from an *irrigated field*, Indio and Mecca, Cal., at the Government Date Gardens.
3. Evaporation in a *dry place* at Indio, Cal.

These illustrate the phenomena which are encountered in the study of evaporation, all of which must be included in the functions exprest by the formula, if it is to be fully satisfactory.

It is seen that the value of C_d at Reno, Nev., for the pans 3, 5, and 7 on each of towers 2, 3, and 4 is about 0.070 in all cases; the same is true on towers 1 and 5. This shows that the formula eliminates that part of the vertical variation which was found to exist when using Bigelow's first formula, as was

TABLE 28.—*C_d-coefficient for August-September, 1907, at Reno, Nev. Evaporation from a small reservoir.*

TOWER 2.

Dates.	A. M. 2	A. M. 5	A. M. 8	A. M. 11	P. M. 2	P. M. 5	P. M. 8	P. M. 11	3-hour means.	4-hour means.
Pan 1, height 0 feet.										
August 1–10	.057	.053	.054	.060	.056	.055	.059	.056	.058	....
12–17	.052	.054	.055	.055	.057	.053	.054	.055	.054	....
19–24	.057	.056	.057	.059	.062	.063	.059	.056	.059	....
26–31	.060	.061	.064	.064	.065	.063	.062	.060	.062	....
September 2–7	.059	.058	.063	.064	.062	.060	.060	.064	.061	....
9–14	.055	.055	.055	.061	.063	.059	.053	.055	.057	....
Means	.057	.056	.058	.061	.061	.059	.058	.056	.056	.074
Pan 3, height 5 feet.										
August 1–10	.071	.074	.075	.075	.061	.056	.062	.071	.068	....
12–17	.056	.077	.071	.068	.077	.065	.058	.064	.067	....
19–24	.074	.081	.092	.082	.082	.068	.068	.072	.079	....
26–31	.060	.074	.077	.072	.063	.057	.059	.056	.070	....
September 2–7	.064	.068	.077	.077	.078	.058	.059	.066	.068	....
9–14	.078	.073	.079	.083	.066	.062	.059	.078	.072	....
Means	.067	.075	.079	.079	.070	.061	.061	.068	.071	.094
Pan 5, height 25 feet.										
August 1–10	.072	.075	.068	.075	.072	.071	.072	.071	.072	....
12–17	.053	.068	.068	.068	.066	.073	.065	.065	.066	....
19–24	.067	.071	.077	.066	.074	.068	.059	.060	.068	....
26–31	.071	.069	.079	.080	.061	.056	.081	.071	.071	....
September 2–7	.069	.072	.076	.077	.065	.056	.062	.061	.067	....
9–14	.071	.074	.076	.078	.067	.052	.056	.072	.068	....
Means	.067	.072	.074	.074	.068	.063	.064	.067	.069	.092
Pan 7, height 45 feet.										
August 1–10	.074	.074	.072	.071	.069	.071	.071	.074	.072	....
12–17	.068	.083	.071	.064	.082	.076	.062	.057	.070	....
19–24	.069	.066	.069	.069	.088	.083	.078	.074	.076	....
26–31	.067	.071	.084	.075	.065	.055	.056	.066	.067	....
September 2–7	.070	.067	.077	.076	.063	.054	.060	.062	.066	....
9–14	.064	.072	.069	.073	.072	.070	.070	.071	.070	....
Means	.069	.072	.074	.071	.073	.068	.066	.067	.070	.093
TOWER 3.										
Pan 1, height 0 feet.										
August 1–10	.058	.054	.053	.054	.059	.064	.666	.062	.059	....
12–17	.055	.054	.059	.057	.052	.056	.054	.056	.057	....
19–24	.054	.055	.060	.063	.063	.062	.065	.062	.061	....
26–31	.053	.053	.065	.067	.062	.056	.049	.048	.057	....
September 2–7	.058	.056	.069	.069	.059	.060	.064	.059	.062	....
9–14	.054	.054	.057	.055	.056	.056	.056	.054	.055	....
Means	.055	.054	.061	.061	.057	.059	.059	.057	.056	.074
Pan 3, height 5 feet.										
August 1–10	.075	.072	.077	.069	.065	.058	.060	.072	.069	....
12–17	.071	.077	.074	.075	.065	.059	.066	.068	.069	....
19–24	.072	.080	.082	.069	.062	.062	.069	.070	.071	....
26–31	.066	.074	.082	.067	.056	.055	.060	.054	.064	....
September 2–7	.059	.071	.071	.062	.069	.061	.061	.055	.064	....
9–14	.066	.072	.079	.072	.066	.060	.067	.070	.069	....
Means	.065	.074	.078	.069	.064	.059	.064	.065	.068	.090
Pan 5, height 25 feet.										
August 1–10	.070	.075	.076	.074	.078	.077	.065	.074	.074	....
12–17	.071	.074	.072	.066	.067	.070	.075	.071	.071	....
19–24	.072	.080	.079	.077	.069	.068	.068	.070	.073	....
26–31	.076	.081	.083	.074	.069	.068	.075	.081	.076	....
September 2–7	.073	.084	.081	.079	.068	.064	.061	.057	.071	....
9–14	.071	.071	.074	.071	.078	.068	.070	.071	.071	....
Means	.072	.078	.078	.074	.071	.069	.069	.071	.073	.097
Pan 7, height 45 feet.										
August 1–10	.076	.078	.068	.067	.077	.085	.071	.073	.076	
12–17	.071	.073	.074	.075	.060	.065	.080	.071	.071	
19–24	.071	.077	.073	.070	.066	.063	.072	.080	.072	
26–31	.077	.080	.075	.074	.067	.057	.065	.073	.071	
September 2–7	.072	.079	.078	.063	.077	.077	.059	.059	.071	
9–14	.066	.071	.079	.074	.066	.063	.074	.076	.071	
Means	.072	.076	.075	.071	.069	.068	.070	.072	.071	.096

TABLE 28.—C_d-*coefficient for August-September, 1907, Reno, Nev.*—Cont'd.

Dates.	A. M. 2	A. M. 5	A. M. 8	A. M. 11	P. M. 2	P. M. 5	P. M. 8	P. M. 11	3-hour means.	4-hour means.
TOWER 4.										
Pan 1, height 0 feet.										
August 1-10	.055	.054	.055	.056	.055	.056	.056	.057	.056	
12-17	.055	.050	.051	.064	.059	.060	.061	.062	.058	
19-24	.061	.053	.052	.051	.056	.064	.067	.061	.058	
26-31	.047	.047	.058	.057	.054	.055	.054	.051	.052	
Se, tember 2- 7	.055	.055	.065	.056	.058	.056	.062	.058	.058	
9-14	.058	.057	.058	.057	.059	.059	.061	.057	.058	
Means	.054	.052	.054	.055	.055	.056	.060	.056	.055	.073
Pan 3, height 5 feet.										
August 1-10	.071	.071	.074	.075	.074	.067	.065	.059	.070	
12-17	.077	.076	.083	.062	.060	.070	.071	.074	.072	
19-24	.072	.075	.075	.072	.064	.063	.064	.076	.070	
26-31	.066	.077	.063	.072	.076	.061	.059	.056	.066	
September 2- 7	.064	.072	.078	.075	.065	.064	.071	.064	.069	
9-14	.063	.066	.069	.075	.079	.066	.064	.062	.068	
Means	.069	.063	.074	.072	.070	.065	.066	.064	.069	.092
Pan 5, height 25 feet.										
August 1-10	.072	.074	.078	.061	.059	.063	.063	.065	.066	
12-17	.072	.077	.081	.061	.063	.063	.080	.076	.072	
19-24	.070	.077	.071	.063	.060	.068	.072	.069	.069	
26-31	.076	.079	.076	.059	.049	.056	.056	.056	.063	
September 2- 7	.073	.076	.071	.065	.055	.056	.066	.066	.066	
9-14	.064	.064	.080	.072	.060	.054	.065	.067	.066	
Means	.071	.075	.075	.064	.058	.060	.065	.067	.067	.089
Pan 7, height 45 feet.										
August 1-10	.068	.072	.069	.076	.071	.068	.060	.059	.068	
12-17	.071	.075	.064	.063	.066	.070	.071	.066	.069	
19-24	.067	.069	.069	.062	.068	.070	.079	.081	.071	
26-31	.078	.082	.072	.064	.059	.058	.063	.071	.068	
September 2- 7	.065	.076	.081	.076	.066	.062	.060	.065	.069	
9-14	.069	.071	.070	.074	.064	.060	.061	.066	.067	
Means	.070	.074	.071	.069	.066	.065	.066	.068	.066	.092

fully explained in the MONTHLY WEATHER REVIEW for February, 1908. On the other hand there is a decided drop in the value of C_d, from 0.070 to 0.056, in passing from pan 3 to pan 1, that is to the surface of the water in the reservoir. It follows that the evaporation at the surface of the water body is $\frac{0.055}{0.070} = 0.82$ of that at a few feet above the surface. This same difference appears on the two-pan stands at Indio and Mecca, where the upper pan is evaporating 1.27 times faster than the one at the surface, after having applied the other functions of the formula. It is not known what should cause these changes in the lower layer of air, as regards the rate of evaporation, but it will be proper to present the facts as they appear in the observations made at Indio and Mecca, south California.

Evaporation observations at Indio and Mecca.

In 1908 the Weather Bureau erected two stations at Indio and Mecca, Cal., in the grounds of the experimental date gardens in charge of the Bureau of Plant Industry, U. S. Department of Agriculture, thru the courtesy of Prof. W. T. Swingle and Prof. S. C. Mason. At each station there was placed a 10-foot stand, carrying a 24-inch pan 10 feet above the ground, together with an anemometer reading in kilometers. On the ground was placed a 72-inch pan, resting upon a solid frame-work of wood that held the bottom flat and horizontal. Regular observations were made at 2, 6, and 10 a. m., and at 2, 6, and 10 p. m., by Mr. A. Stumph, at Indio, from July 8 to November 4, 1908; and by Mr. J. L. Southerland, at Mecca, from July 10 to November 8, 1908. These date gardens are irrigated to a moderate amount and the ground is kept a little moist, tho not so wet as in an irrigated alfalfa field, such as that in which were made observations at Reno, Nev., in 1907. Furthermore, at Indio, Cal., near the Southern Pacific Railroad station, a series of observations on five pans were maintained by Dr. C. Abbe, jr., from October 7 to November 10, 1907, concerning which further remarks will be made in a later paragraph.

TABLE 29.—*Evaporation observations at Indio and Mecca, Cal.,* C_d-*coefficient for July-December, 1908. Evaporation over an irrigated field.*

Series.	Pan (1), on ground. A. M. 2	A. M. 6	A. M. 10	P. M. 2	P. M. 6	P. M. 10	Means.	Pan (2), 10 feet above ground. A. M. 2	A. M. 6	A. M. 10	P. M. 2	P. M. 6	P. M. 10	Means.
U. S. DATE GARDEN, INDIO, CAL., (Stumph).														
0-10 1	.052	.055	.054	.054	.054	.049	.053	.078	.075	.075	.069	.078	.074	.075
2	.056	.061	.056	.043	.042	.038	.049	.073	.088	.083	.081	.065	.060	.076
3	.057	.062	.045	.054	.044	.041	.050	.097	.088	.089	.088	.099	.099	.093
4	.041	.048	.059	.045	.051	.039	.047	.082	.074	.100	.066	.056	.085	.077
10-20 5	.029	.055	.078	.079	.047	.031	.054	.041	.073	.108	.130	.083	.045	.080
6	.055	.058	.046	.046	.056	.070	.055	.074	.071	.066	.088	.085	.096	.080
7	.066	.065	.035	.039	.039	.037	.047	.101	.077	.076	.092	.065	.087	.083
8	.049	.055	.046	.055	.050	.060	.052	.064	.079	.073	.086	.093	.079	.079
9	.063	.045	.048	.056	.063	.062	.056	.108	.092	.190	.111	.108	.107	.104
U. S. DATE GARDEN, MECCA, CAL., (Southerland).														
0-10 1	.047	.052	.059	.064	.060	.049	.055	.066	.063	.089	.082	.092	.080	.079
2	.045	.051	.045	.041	.057	.045	.047	.080	.094	.095	.093	.092	.078	.089
3	.046	.051	.054	.056	.048	.042	.050	.074	.074	.079	.090	.079	.078	.078
4	.051	.058	.056	.052	.042	.042	.050	.105	.109	.085	.100	.100	.089	.098
10-20 5	.053	.057	.057	.051	.043	.052	.052	.088	.067	.088	.088	.078	.069	.080
6	.048	.045	.041	.045	.044	.049	.045	.082	.091	.090	.089	.081	.081	.086
7	.046	.049	.050	.046	.046	.046	.047	.071	.074	.081	.083	.082	.078	.078
8	.058	.053	.057	.048	.051	.046	.052	.074	.068	.075	.081	.081	.099	.080
9	.049	.049	.046	.040	.049	.046	.047	.058	.066	.064	.075	.085	.072	.070

TABLE 30.—*Examples of the 4-hourly amounts of evaporation, E_o, from which the above values of C_d have been computed.*

INDIO, DATE GARDEN.

Series.	Pan (1), on ground.							Pan (2), 10 feet above ground.						
	A. M.			P. M.			Total E_o.	A. M.			P. M.			Total E_o.
	2	6	10	2	6	10		2	6	10	2	6	10	
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1	.145	.113	.153	.261	.273	.181	1.126	.200	.156	.243	.371	.460	.313	1.743
2	.125	.104	.164	.228	.268	.170	0.954	.163	.155	.242	.430	.420	.273	1.683
MECCA, DATE GARDEN.														
1	.141	.143	.181	.280	.312	.196	1.253	.200	.173	.285	.420	.493	.320	1.951
2	.160	.130	.146	.249	.300	.227	1.212	.220	.180	.244	.426	.467	.347	1.884

TABLE 31.—*Evaporation observations at Indio, Cal., October–November, 1907; in a very dry field.* (Abbe.)

Dates.	C_d-coefficient.							Evaporation $= E_o$						
	2 a. m.	6 a. m.	10 a. m.	2 p. m.	6 p. m.	10 p. m.	Means.	2 a. m.	6 a. m.	10 a. m.	2 p. m.	6 p. m.	10 p. m.	Totals.
PAN 1. 24-inch, buried to the rim in the sand.														
								Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
October 7–11	.034	.032	.030	.031	.028	.029	.031	.120	.087	.093	.163	.187	.150	.800
12–16	.034	.030	.033	.038	.034	.037	.034	.090	.070	.090	.121	.116	.121	.608
17–21	.033	.034	.037	.027	.031	.032	.032	.066	.058	.069	.076	.096	.080	.445
22–26	.036	.031	.039	.026	.037	.022	.032	.068	.046	.066	.065	.103	.050	.398
27–31	.037	.035	.029	.026	.025	.033	.031	.074	.063	.060	.095	.101	.087	.480
November 1–5	.037	.034	.028	.022	.023	.032	.029	.102	.070	.069	.100	.116	.115	.572
6–10	.035	.038	.038	.023	.030	.040	.033	.082	.070	.077	.066	.101	.113	.509
Means	.035	.033	.033	.028	.030	.032	.032	.086	.066	.075	.098	.131	.102	.545
PAN 2. 22-inch, on platform, rim 10 inches above ground.														
October 7–11	......	......	......	......	......	......	......	......	......	......	......	......	......	......
12–16	.038	.037	.032	.032	.024	.026	.032	.076	.063	.072	.121	.117	.094	.548
17–21	.026	.021	.021	.025	.037	.027	.026	.042	.028	.033	.078	.118	.061	.355
22–26	.033	.029	.031	.033	.028	.034	.031	.049	.034	.043	.081	.078	.069	.354
27–31	.039	.035	.034	.024	.029	.033	.032	.064	.044	058	.094	.123	.085	.468
November 1–5	.034	.034	.021	.023	.026	.032	.028	.074	.050	.041	.115	.146	.111	.537
6–10	.032	.025	.031	.026	.027	.029	.028	.053	.035	.048	.067	.083	.066	.352
Means	.034	.030	.028	.027	.028	.030	.029	.060	.042	.049	.092	.111	.081	.435
PAN 3. 26-inch, on platform, rim 10 inches above ground.														
October 7–11	.031	.028	.030	.031	.029	.028	.030	.090	.058	.092	.185	.200	.136	.762
12–16	.034	.035	.032	.027	.027	.035	.032	.076	.065	.078	.103	.106	.105	.533
17–21	.032	.027	.030	.029	.638	.021	.029	.052	.034	.016	.079	.112	.044	.367
22–26	.034	.029	.033	.034	.032	.022	.031	.052	.034	.046	.079	.082	.044	.337
27–31	.039	.034	.024	.025	.031	.040	.032	.065	.043	.041	.085	.115	.095	.444
November 1–5	.031	.031	.030	.024	.026	.031	.029	.072	.047	.059	.109	.131	.100	.518
6–10	.028	.022	.028	.028	.031	.022	.027	.048	.031	.052	.079	.092	.052	.354
Means	.033	.029	.030	.028	.031	.029	.030	.065	.045	.059	.103	.120	.082	.475
PAN 4. 72-inch, on platform, rim 10 inches above ground.														
October 7–11	.029	.027	.028	.024	.021	.025	.026	.086	.060	.075	.117	.130	.116	.584
12–16	.034	.027	.031	.025	.026	.039	.030	.080	.052	.071	.087	.100	.117	.507
17–21	.022	.025	.026	.024	.033	.021	.025	.038	.035	.040	.063	.103	.052	.331
22–26	.028	.023	.027	.029	.030	.024	.027	.043	.029	.037	.064	.075	.047	.295
27–31	.032	.029	.032	.024	.030	.033	.030	.057	.038	.051	.074	.105	.080	.405
November 1–5	.031	.028	.029	.024	.025	.028	.028	.066	.043	.055	.095	.108	.080	.447
6–10	.029	.027	.032	.033	.025	.031	.028	.051	.041	.053	.081	.069	.068	.363
Means	.029	.027	.029	.026	.027	.029	.029	.060	.043	.055	.083	.099	.080	.419
PAN 5. 24-inch, on platform, rim 2 feet above the ground.														
October 7–11	......	......	......	......	......	......	......	......	......	......	......	......	......	......
12–16	.035	.035	.032	.025	.035	.037	.033	.078	.066	.085	.108	.154	.114	.605
17–21	.026	.022	.029	.041	.036	.021	.029	.041	.027	.050	.135	.117	.050	.420
22–26	.026	.026	.025	.040	.029	.027	.029	.039	.036	.041	.082	.087	.058	.343
27–31	.040	.037	.026	.038	.029	.035	.034	.064	.045	.045	.161	.133	.088	.536
November 1–5	.040	.039	.021	.030	.023	.034	.031	.084	.056	.044	.168	.142	.113	.607
6–10	.024	.023	.028	.023	.030	.026	.026	.048	.032	.045	.069	.099	.066	.359
Means	.032	.030	.027	.033	.030	.030	.030	.059	.041	.052	.121	.122	.082	.478
Means	.033	.030	.029	.028	.029	.030	.030	.066	.048	.058	.099	.117	.085	.471

These values of E_o, the observed amount of evaporation in 4-hour intervals, are typical of the quantities from which C_d has been deduced by an inversion of these formula.

The observations at the Indio and Mecca date gardens, made by Stumph and Sutherland, were assorted at the time of the observing into three groups according to the wind velocities, so that they should fall into three sets according as the mean wind velocity for the producing four hours lay between the intervals 0–10, 10–20, 20–40 kilometers per hour, respectively (see Table 29, column 1). Since the wind velocity changes considerably in the course of the day, it frequently happens that the observations for the same date are entered under different wind groups. They were entered as they were thus assorted under the six observation hours until about ten observations were collected for the same pan at the same hour. The meteorological conditions were approximately the same from day to day in that climate and the ten observations were brought together in this computation of C_d. It is evident that while there is a test of value of the adopted coefficient, $A = 0.0175$, determined at Reno, Nev., this is, in some cases, at the expense of the uniformity of the C_d-coefficient in the course of the day. Table 29 contains the values of C_d for 9 series at Indio and for 9 series at Mecca, and they show that there is no important change of C_d with the velocity of the wind. Series 9 on Pan 2 at Indio is larger, but Series 5 on Pan 2 at Mecca is smaller, while the other variations in these series are such as may be expected. The mean values of C_d for Indio and Mecca, are:

$$\left.\begin{array}{ll}\text{Pan (1) on the ground,} & C_d = 0.052 \\ \text{Pan (2) about 10 feet above the ground,} & C_d = 0.080\end{array}\right\} \text{Ratio } 1.54.$$

The similar data obtained at the dry place near the Southern Pacific Railway station, as given in Table 31, produces for the pans on the ground, $C_d = 0.030$. Reducing the values of C_d found at Reno, Nev., for the three-hour intervals to corresponding four-hour intervals by the factor 133, we find for—

$$\left.\begin{array}{ll}\text{Pan (1) on the water surface,} & C_d = 0.098 \\ \text{Pans (3), (5), (7) above the water,} & C_d = 0.124\end{array}\right\} \text{Ratio } 1.27.$$

Collecting these results, we have for the several coefficients:

	Pan on surface.	Pan 5–10 feet higher.
Evaporation over a water surface,	$C_d = 0.098$	$C_d = 0.124$
Evaporation in an irrigated field,	$C_d = 0.052$	$C_d = 0.080$
Evaporation in a very dry place,	$C_d = 0.030$	$C_d =$ ——

These data constitute a very difficult problem in evaporation, according to this formula. After having eliminated the large diurnal variation, already illustrated in Paper III of this series, MONTHLY WEATHER REVIEW, February, 1908, as well as the variation which exists from 5 to 45 feet above the water of the Reno reservoir, there *yet remains in the layer of air next to the ground 5 to 10 feet thick*, a remarkable discontinuity in the values of this coefficient. Not only is the value of C_d larger at 10 feet above the surface than it is at the surface itself, but the coefficient increases from the dry place thru the moderatly irrigated field to the reservoir water surface. A diligent examination of all our available data, surface temperatures S, air temperatures t, and t_1, vapor pressure e_s and e_d, as well as e_r, fails to disclose any apparent connection between them. Had the coefficient C_d happened to be *constant* it would have meant that the adopted formula is satisfactory. As matters stand this variation in the C_d-coefficient in the lower layer of air and with the local climatic conditions seems to call for an extended research for the missing term. I have accordingly, with this end in view, organized the campaign for the year 1909 by placing two-pan stands 10 feet high at each station, and locating three types of stations, (1) over a water surface, (2) over an irrigated field, and (3) in a very dry place. As already stated the stations are extended to cover 16 points of the United States.

(5) VARIATIONS IN THE EVAPORATION AT THE SAME PLACE.

It has been stated that difference in the size of the pans is an important factor in the rate of the evaporation at the same place. To test this point, and at the same time to show the effect of the relation of the location of the pan near the ground to the amount of evaporation, was the purpose of the experiment by Dr. C. Abbe, jr., near the Indio railroad station. Five pans were employed, and they were placed close to each other on the ground or near it. They were, therefore, under the same wind influences for each pan and the same general climatic conditions. The previous work at Reno was designed to test the effect of the vapor blanket overlaying a water surface, upon the evaporation from pans placed in different parts of it. This work at Indio entirely eliminated the vapor blanket effect, and the wind effect so far as any differential results are concerned. The pans were of the same depth, 10 inches in all cases, and their diameters and positions relative to the sand that formed the ground at that point were as follows:

Pan (1), 24-inch, buried up to the rim in the sand.

Pan (2), 22-inch,
Pan (3), 26-inch, } standing on a platform, the rims about 10 inches from the ground.
Pan (4), 72-inch,

Pan (5), 24-inch, standing on a platform; the rim 2 feet from the surface of the sand.

The right-hand half of Table 31 gives the mean values of the evaporation for the five-day intervals noted in the first column, as observed every four hours. A few interpolations at night were made by separating some eight-hour intervals into two four-hour intervals, 10 p. m.–2 a. m., and 2 a. m.–6 a. m., but the totals for the day are the same, and this is the only important consideration in this connection. The totals are given in the last column, and the means are taken for the entire interval, October 7 to November 10, 1908.

It is noticed that the C_d-coefficient, as given to the left hand half of Table 31, seems to be very consistent for the series thruout the day and for the five pans, as might be expected, since they stand in a dry place on nearly the same level. The general result is that the total daily amount of the evaporation at the several pans averages,

Pan (1), 24-inch, buried to the rim in the ground, 0.545 cm.
Pan (2), 22-inch, standing on the ground, 0.435 cm.
Pan (3), 26-inch, standing on the ground, 0.475 cm.
Pan (4), 72-inch, standing on the ground, 0.419 cm.
Pan (5), 24 inch, raised in the air above ground, 0.478 cm.

These two remarkable features are that the 24-inch pan buried in the ground loses 0.545 centimeters per day, and the 72-inch pan standing on the ground loses 0.419 centimeters per day. The 72-inch pan on the ground loses only 77 per cent of the 24-inch buried pan. The pans were placed so that the four small pans touched the large 6-foot pan as it were at points 90 degrees apart, except for the differences in the elevation. It has been the custom to bury pans in the ground, but it is here shown how different results can be obtained under the same meteorological conditions by such a difference of position. In order to exhibit the primary cause of this variation in the amount of the evaporation it is only necessary to bring together the mean surface temperatures for the five pans during the interval, October 7–November 10, 1907, at each of the six hours of the observations.

TABLE 32.—*Relation between water surface temperature S and E_o.*

Pans.	2 a. m.[2]	6 a. m.	10 a. m.	2 p. m.	6 p. m.	10 p. m.	Means.	E_o
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	Cm.
(1)	19.9	18.7	22.3	26.8	25.1	22.4	22.5	0.545
(2)	17.6	15.8	21.1	26.5	24.1	20.2	20.9	0.435
(3)	17.9	16.0	21.9	26.5	24.3	20.7	21.2	0.475
(4)	17.6	15.2	21.0	25.6	24.0	20.6	20.7	0.419
(5)	18.0	16.1	22.7	27.9	24.9	20.7	21.7	0.478

[2] Interpolated values.—*C. A., jr.*

It is evident that the sequences in the temperatures S of the water surface and in the amount of evaporation E_0 are parallel and in a nearly equal proportion. The inference is that whatever caused the change in the temperature of the water thereby directly influenced the evaporation. By plotting the temperatures S it is seen that for pan (1) the temperature remained higher than the others during the night because, being buried in the sand, it was kept warmer by the continuous conduction of heat from the ground which, at the depth of 10 inches, cooled slower than the air above it. Pan (5), located 2 feet above the surface and surrounded by the free air, went to a higher temperature at its maximum about 2 p. m. than did the other pans, but it cooled off quicker than did pan (1). Pan (4), 6 feet in diameter, was the coolest of all for the entire day, and it is supposed to have acted somewhat like an umbrella to the ground underneath it and so have remained relatively less heated as a whole. These examples show the extreme difficulty, if not impossibility, of transferring the results of the evaporation in pans from one point to another. It is only safe to measure the temperature of the water surface *in situ*, and we shall adhere to this principle thruout the remainder of the research.

We have shown that the following terms enter vitally into an evaporation formula:

S, water surface temperature, centigrade.

t, dry-bulb temperature of the air, centigrade.

t_1, wet-bulb temperature of the air, centigrade.

w, wind velocity, in kilometers per hour.

Besides these, there are apparently some unknown terms concealed in the C_d-coefficient. This may involve certain very difficult physical processes, like diffusion and mixture of gases.

(6) THE PRACTICAL APPLICATION OF THE EVAPORATION FORMULA.

Mr. C. E. Grunsky expressed the view in Engineering News, Vol. 60, No. 7, August 13, 1908, that a formula of the above class, involving several variables, will fail to meet the requirement of the ordinary engineer, because he will not have before him the observational data needed for its evaluation. It is necessary to infer from the results collected in this series of papers that not only will the complete solution of the problem be difficult in itself, but also that the integration of the amount of the evaporation over a large body of water in a variable climate, especially where precipitation occurs irregularly, is a task of unusual difficulty. Until a final broad formula is secured, it is merely a matter of speculation to conjecture how much it can be simplified in practice. It is very possible that the average monthly amount of evaporation can be computed approximately from the mean monthly values of the meteorological elements. We can here show how the average daily evaporation can be computed from the mean daily meteorological values, as given above, provided the C_d-coefficient is known. Without that factor, the computation fails. But this coefficient can evidently be secured from a very few days of actual observing at a given locality, and then it can be applied to the meteorological data. Indeed, it is not too much to say that, having the C_d-coefficient, the amount of evaporation can be followed more accurately from the metoorological data than from the measurements in pans, subject to all sorts of disturbing conditions. The following table will show how to abbreviate the daily work of observing and computing, as assisted by Bigelow's Manual for Observers in Climatology and Evaporation, Weather Bureau, Washington, 1909.

TABLE 33.—*Abbreviation of the computation by using the mean daily values.*

Example from Table 25.

	A. M.				P. M.				Total. E_o	Daily means.	$\frac{5a+2p}{2}$
	2	5	8	11	2	5	8	11			
									Cm.		
S	15.3	15.7	18.6	22.2	22.2	19.9	17.3	16.0	....	18.4	19.0
e_d	7.1	7.3	8.1	7.5	8.0	7.6	6.9	7.0	....	7.4	7.7
w	12	7	3	9	13	25	23	17	....	14	14
E_1	0.15	0.15	0.20	0.32	0.30	0.24	0.20	0.17	....	0.21	0.22
E_2	.03	.02	.01	.05	.07	.11	.08	.05	....	.05	.05
E	.18	.17	.21	.37	.37	.35	.28	.22	....	.26	.27
E_m	.200	.175	.190	.290	.370	.365	.315	.250	....	2.08	2.16
E_o	.110	.100	.105	.155	.210	.190	.170	.140	1.180	1.144	1.188
0.100 C_d	.055	.057	.055	.053	.057	.052	.054	.056	....	....	....

Mean 0.100 C_d=0.055.

S, observe the water temperature for a series of hours.

e_d, observe t and t_1, dry and wet-bulb air temperatures.

w, read the anemometer and compute the average velocity per hour.

E_1, E_2, Manual Tables VI and VII. $E=E_1+E_2$. E_m=means of pairs.

E_o, observed evaporation in 3-hour intervals.

C_d, $E_o/E_m = C_d$. Apply factor 0.100, due to the construction of the tables.

In the last column but one write down the mean values of S, e_d; from the data on the same line, adopt the same value of the w from the anemometer; compute E_1, E_2, E; multiply E by 8 for a time interval of twenty-four hours instead of three hours; multiply 2.08 by 0.055 and obtain 1.144 centimeters for the computed total evaporation for the day in place of 1.180 centimeters, as observed.

In the last column take the mean of the minimum and maximum values of S, e_d as observed at 5 a. m. and carry thru the computation to 1.188 centimeters. Now invert the process: Observe the total daily evaporation for twenty-four hours apart, as at 6 a. m., on two successive days. Observe the anemometer at two times twenty-four hours apart and divide the difference in the anemometer readings by 24 for w. Observe S, t, t_1 at about 6 a. m. and 3 p. m. Compute e_d at 6 a. m. and 3 p. m. Take the mean values of S and e_d. Compute E. Then $C_d = \frac{E_o}{8E}$.

In this way two observations at about 6 a. m. and 3 p. m. in summer, gradually contracting the time to 7 a. m. and 2 p. m. in winter, are capable of producing a very valuable result. It is desirable to have observations at 2, 6, and 10 a. m. and 2, 6, and 10 p. m., and at as many stations as possible, certainly at one station of each of the large reclamation projects. At the other stations on the same project, if it is not convenient to secure good observers to do the work for the complete set, six times daily, or five times, omitting the 2 a. m. observation. The hours of the observations can be limited to 6 a. m. and 3 p. m., these being near the minimum and maximum water temperatures. It is evidently necessary to find values for C_d in many localities in order to arrive at a general formula of evaporation applicable under all conditions.